Water Temperature Observation on 1000 km Square Scale Using Ocean Acoustic Tomography Systems

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1. INTRODUCTION

After Munk and Wunsh[1)] reported, in 1979, about the possibility of a large scale ocean monitoring by ocean acoustic tomography, much effort was devoted to realizing tomography observations. Japan Marine Science and Technology Center (JAMSTEC) started the research project for ocean acoustic tomography ten years ago[2)] and developed five 200 Hz transceiver systems in March 1997.[3)] These systems are designed to be able to observe ocean phenomena in the 1000 km range in real -time basis. A giant magnetostrictive source was developed for increasing the transmitting level and decreasing the size of the source to realize an observation in the 1000 km range and for two years long.[4)] Observed data are transferred via the INMARSAT-C communication link from the surface buoy to our laboratory on a real-time basis. Ocean current can be measured by two way sound propagation. Three-dimensional temperature distribution can be visualized in time sequence by the data analysis of an inverse method.

2. 200 HZ TRANSCEIVER SYSTEM

2.1 Giant magnetostrictive source

Ocean acoustic tomography makes it possible to observe the ocean current and water temperature distributions in a wide area. We evaluated the sound pressure level and the optimum frequency to realize a 1000 km propagation for ocean acoustic tomography by the sonar equation. We will evaluate the sound pressure level and the optimum frequency to realize a 1000 km propagation using the following sonar equation.

$$SL = TL + NL - (PG - L) - AG + SNR + AF \qquad (1)$$

where,

SL ; Transmitting level (re 1 µPa at 1m)
TL ; Propagation Loss (by Mellen's equation[5)])
NL ; Ambient noise level (re 1 µPa)
(Beaufort level 5 in Wentz' spectrum level[6)])
PG ; Processing gain (re 1 s)
(for the correlation of M-sequence signal)
L ; Dulling of peak level
(the effect of the bandwidth of the source)
AG ; Receiving array gain (=7 dB for 5 elements)
SNR; Signal to noise ratio[7)] (> 15 dB)
A*F* ; Margin for amplitude fading[8)] (= 10 dB)

These parameters are dependent on frequency except *AG* and *AF*. The result calculated between 150 Hz to 400 Hz for 1000 km propagation is shown in Fig.1. As the effect of the ship noise exceeds the wind noise below 100 Hz,[9)] it is confirmed that the optimum frequency for the 1000 km propagation is around 200 Hz. It is found that *SL* is about 190 dB at 200 Hz in the case of Q=4.

A giant magnetostrictive material was made of the alloy of rare-earth metals (Tb, Dy)Fe_2. It has more than ten times the magneto-strain and less than one fourth of

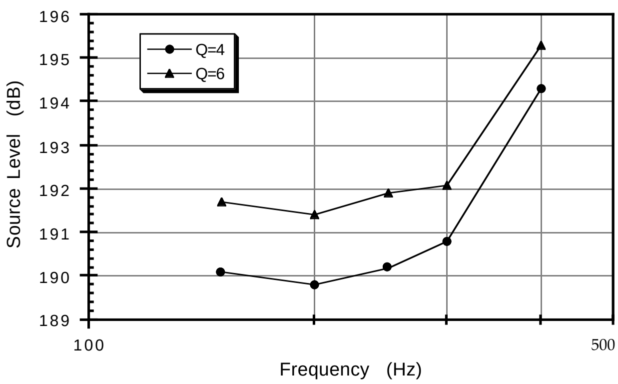


Fig.1 Optimum frequency for 1000 km sound propagation at the case of Q=4 and 6 calculate by eq.(1).

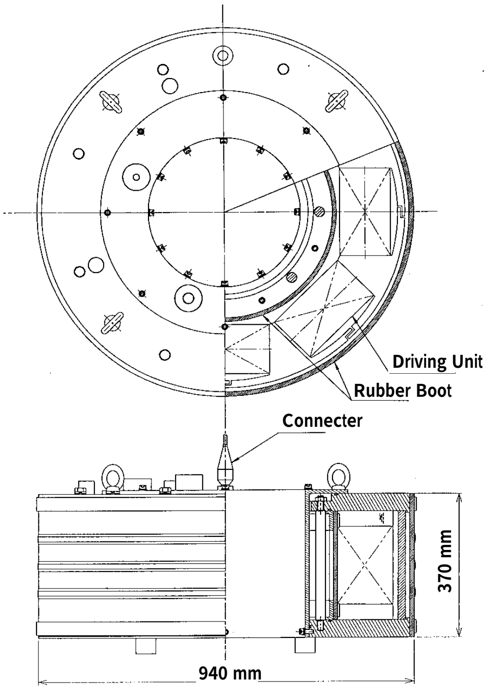


Fig.2 The 200 Hz source using eight driving units of giant magnetostrictive materials.

Young's modulus in comparison with conventional magnetostrictive materials. It means that a small size and high power sound source can be realized. We constructed a driving unit using a giant magnetostrictive rod which has the diameter and the length of the rod are 20 mm and 120 mm respectively. The source with a pulsating barrel shape vibrates in the radial mode of octagonal radiating plates connected to eight driving units. Outer and inner sides of the cylindrical source are covered with rubber boots and filled with oil for pressure balance in deep sea use. The height of the source is 370 mm and the diameters of outer and inner boots are 940 mm and 560 mm respectively as shown in Fig.2. Inside of the inner boot, a cylindrical air cavity with 50 mm thick is mounted for insulation of a backward radiation of sound and for reduction of the stiffness of the source. A pressure compensator is used to keep the volume of the air cavity to be constant for depth fluctuation of the source. The weight of the source is 410 kg and the pressure compensator is 280 kg.

Some experiments were conducted to measure the acoustic characteristics of the source at the depth around 1000 m in the sea . The source and the measurement system which is a hydrophone and a recorder are suspended from

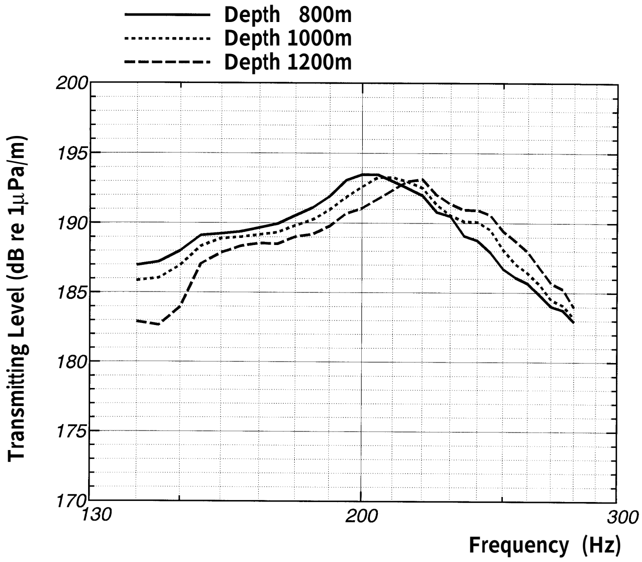


Fig.3 Frequency characteristics of transmitting level for the 200 Hz sound source measured at depths of 800 m, 1000 m and 1200 m in the ocean.

the test ship at the depth between 800 m to 1200 m. Figure 3 shows frequency characteristics of the sound pressure level as a function of the frequency and the depth. The maximum level of 193 dB (re. 1μPa at 1m) could be gained at each depth. The Q values are less than 4, which means the frequency band width over 50 Hz, at all depths measured in this experiment.

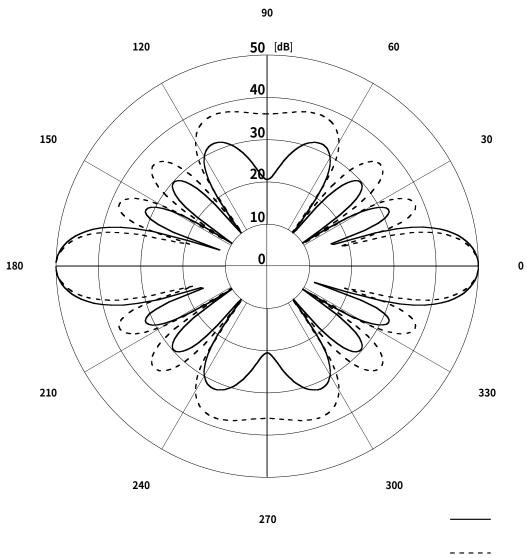


Fig.4 Calculated beam patterns for the 200 Hz receiving array of 0° direction with the Kaiser-Bessel shading (solid line) and without shading (bloken line).

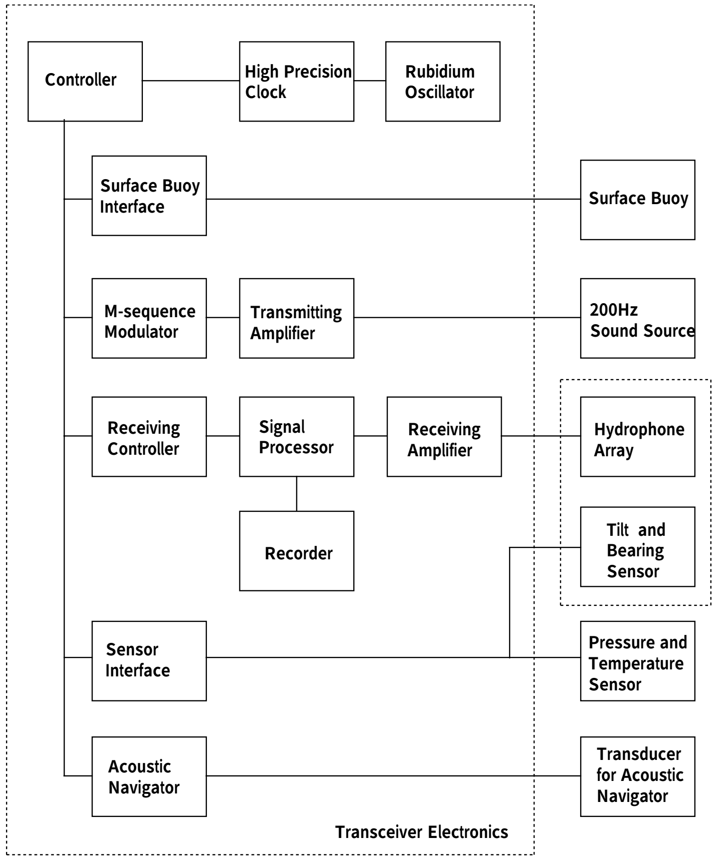


Fig.5 Block diagram for electronics in the 200 Hz transceiver and some external equipments.

2.3 Hydrophone array

The hydrophone array consists of five hydrophone elements and pre-amplifiers placed at intervals of 5.7m which corresponds to three quarters of the wavelength of 200Hz. The length of the array is 27m and the diameter is 5 cm which is filled with oil for pressure balance. The beam width of the array is about 20 degrees as shown in Fig.4. A tilt and bearing sensor is mounted at the end of the array for a beamforming using the signals of five hydrophones mentioned below.

2.4 Block diagram

As shown in Fig.5, the electronics in the transceiver are constructed from a high precision quarts clock with a Rubidium oscillator, a surface buoy interface for the communication with a surface buoy, a M-sequence generator and a power amplifier for a sound source, an analog and digital section of the receiver, a hard disk, a sensor interface for the hydrophone array, pressure and temperature sensor, and an acoustic navigator for transponders. The time schedule of the operation , such as the timing of the sound transmission and reception, is written in the memory of the high precision clock. Each block is usually sleeping except the clock. After the clock makes awake the controller, the controller conducts the control command of each block.

2.5 Data processing flow

Received data are processed in the transceiver as shown in Fig.6. Signals received by a hydrophone array are first summed periodically to improve the S/N ratio. We use the M-sequence signal of 1023 digits with the repetition of 14 times. The total length of the signals is about 150 sec. Then a beamforming is carried out to discriminate the sound rays incident on the hydrophone array from the upper 10 degree and lower 10 degree directions. The data after beamforming are correlated with the replica of the M-sequence signal and the arrival time and amplitude of the peaks are detected . Peak data are recorded on a hard disk and sent to a surface buoy at the same time. Received data before beamforming can be also recorded on a hard disk selectively. INMARSAT-C transceiver and GPS receiver are mounted in the surface buoy to transmit the data to the land station and to correct the clock in the transceiver respectively.

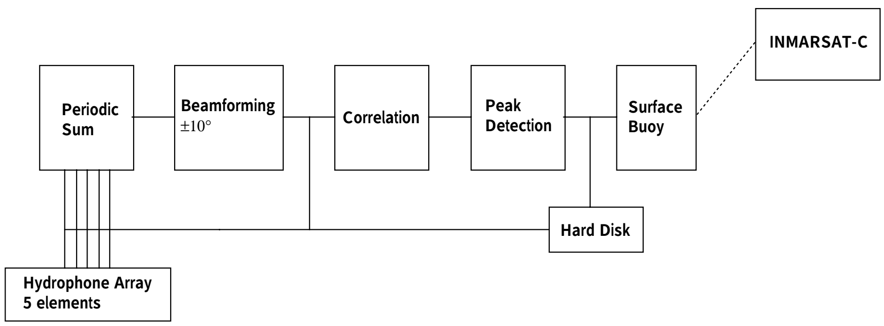


Fig.6 Data processing flow for the received signal by the hydropne array in the 200Hz transceiver.

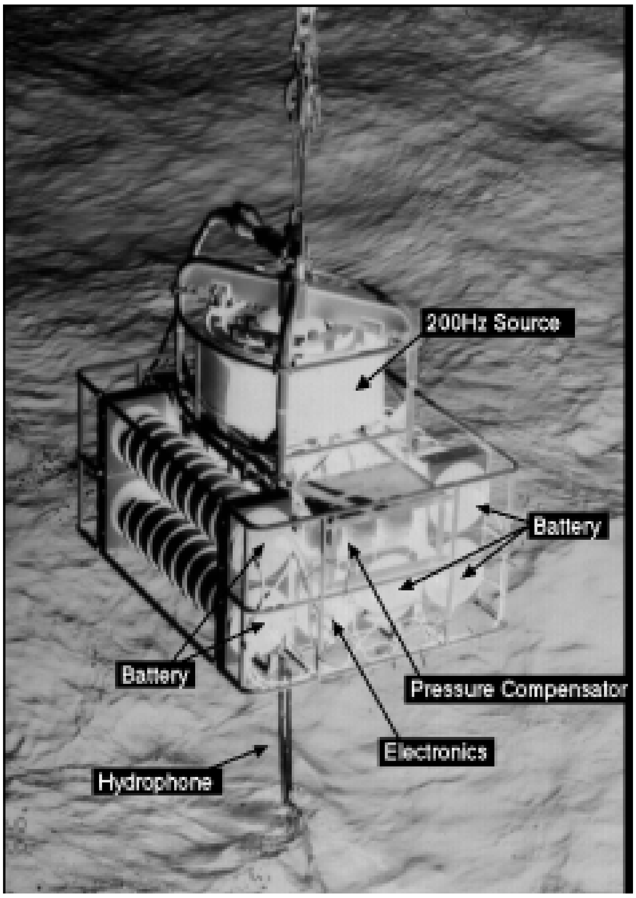


Fig.7 200 Hz tomography transceiver constructed from a 200 Hz sound source, a pressure compensator, an electronics and five battery cases and a hydrophone array.

2.6 Mooring system

A 200 Hz tomography transceiver consists of a 200 Hz giant magnetostrictive source, a hydrophone array with the length of 30 m, several pressure vessels for electronics and batteries, and a pressure compensator for the source as shown in Fig.7. Figure 8 shows the mooring system for a 200 Hz transceiver. The 200 Hz transceiver weights 750 kg in water and is moored by two syntactic foam floats,buoyancy of which is about 1.5 ton. Received data by a hydrophone array is processed digitally in the transceiver and sent to a surface buoy through a transmitting cable with the length of 3000 m. The transmitting cable is supported in a profile of the letter "S" by sub-floats and weights attached on the way of the cable to absorb the fluctuation of a surface buoy on the sea surface. The fluctuations of the transceiver in the ocean are measured by three acoustic transponders deployed on the seafloor.

3. SEA TRIALS FOR FIVE TRANSCEIVER SYSTEMS

3.1 Experimental area

In July 1997, we started sea trials to observe the Kuroshio Extension in the east of Izu-Ogasawara Trench shown in Fig.9 using of the five 200 Hz transceiver systems. Five transceivers were moored at a depth of about 1100 m at S1 through S5 in Fig.9. The diagonal dimension of the pentagon was about 1000 km. Each transceiver transmitted the 200 Hz M-sequence signal every 6 hours and received the signals propagating from the other four

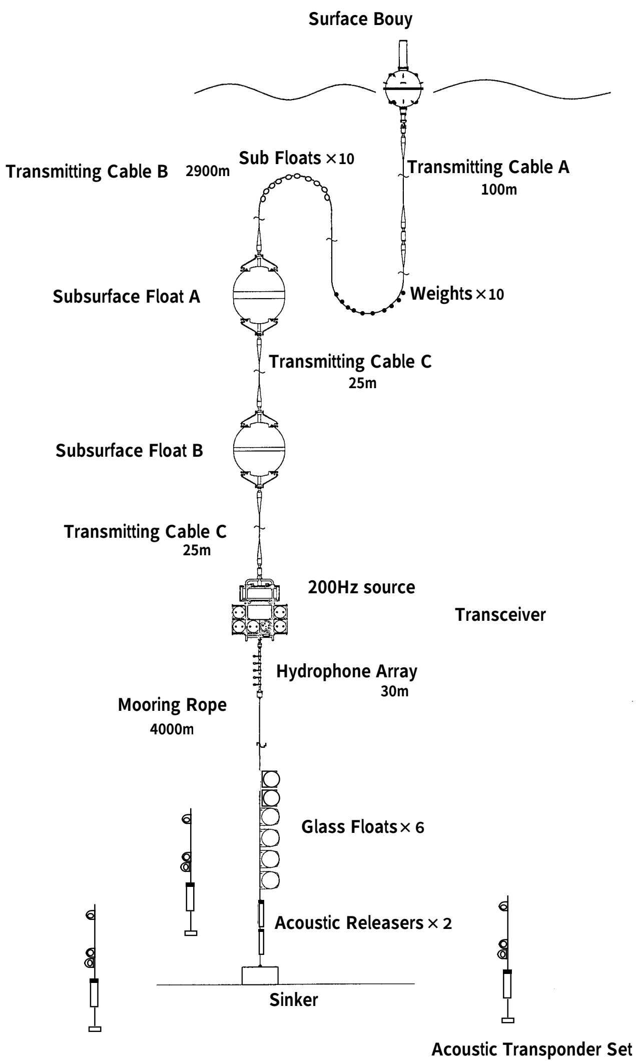
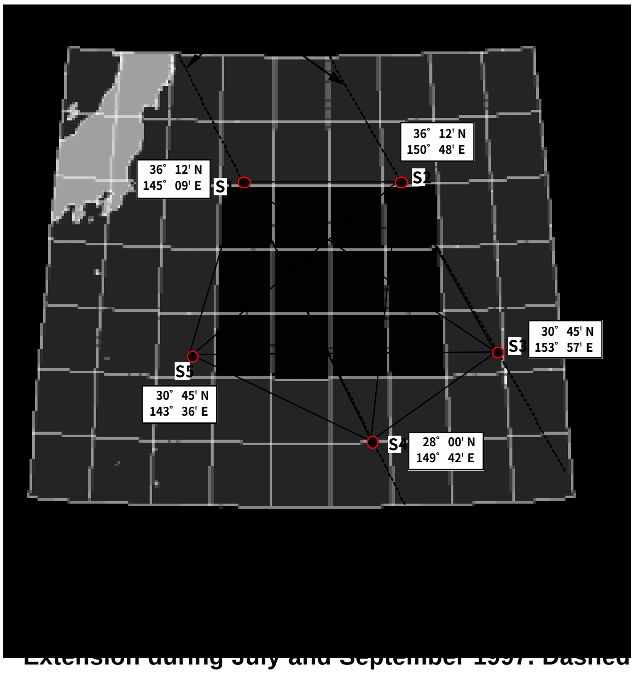


Fig.8 Mooring system for the 200 Hz tomography transceiver and three acoustic transponders.



Extension during July and September 1997. Dashed lines show the orbit of the TOPEX/Posendon altimeter satelllite.

transceivers. All the transceiver systems were recovered in September 1997 successfully. Sea truth data were also obtained at every 50 km distance by XBT (expendable bathythermograph) and by CTD (conductivity, temperature and depth sensor) at the cross points of the diagonals of the pentagon.

3.2 3-D profiles of the water temperature

At first, eigen ray paths between each transceiver were predicted by a ray tracing method using the observed level profiled data in July by NODC and the topography data by the ETOPO5. Figure 9 shows the calculated 48 ray paths from S1 to S5. It is found that upper and lower turning points of the acoustic rays are spread between surface and bottom in this figure. It means that all the information in the cross section between surface and bottom can be estimated by the inversion as follows. Next, a ray identification is conducted by connecting the pulse tranins predicted from ray paths with observed pulses. An example of the waterfall display of the received pulse trains is shown in Fig.10 which are signals from S1 to S5 received during 13 o'clock on July 13 and 20 o'clock on July 14. The propagation time between S1 and S5 are almost concentrated within the time range of 413 - 414 sec in which 10 groups of rays can be distinguished.

A perturbation of the sound velocity δc is defined as a difference between measured sound velocity and a reference one predicted by the data of the NODC. Trigonometric functions in horizontal direction and an empirical orthogonal functions in the vertical direction are used in the analysis by a stochastic inverse method. Typical examples of the results estimated during August 1 and 31 are shown in Fig.12. The time series of the 3-D temperature distributions can be obtained every six hours which yields the fluctuation of the Kuroshio Extension in this region clearly as shown in this figure, the horizontal plane is sliced at a depth of 200 m to indicate the internal temperature distribution.

5. CONCLUSION

Five 200 Hz tomography transceiver systems were

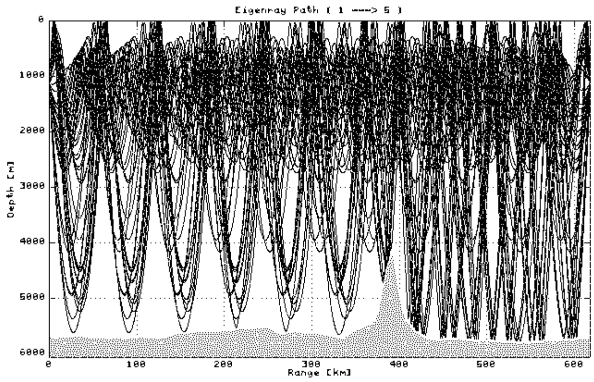


Fig.10 Eigen ray paths from S1 to S5 calculated using the observed level profile data by NODC and the

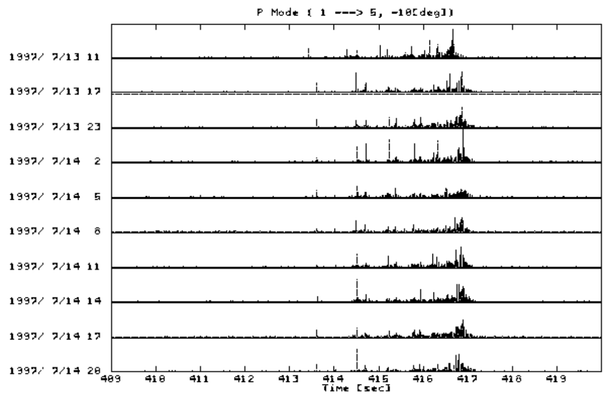


Fig.11 Correlated pulse trains received by S5 from S1 transmission during 13 o'clock on July 13 and 20 o'clock on July 14.

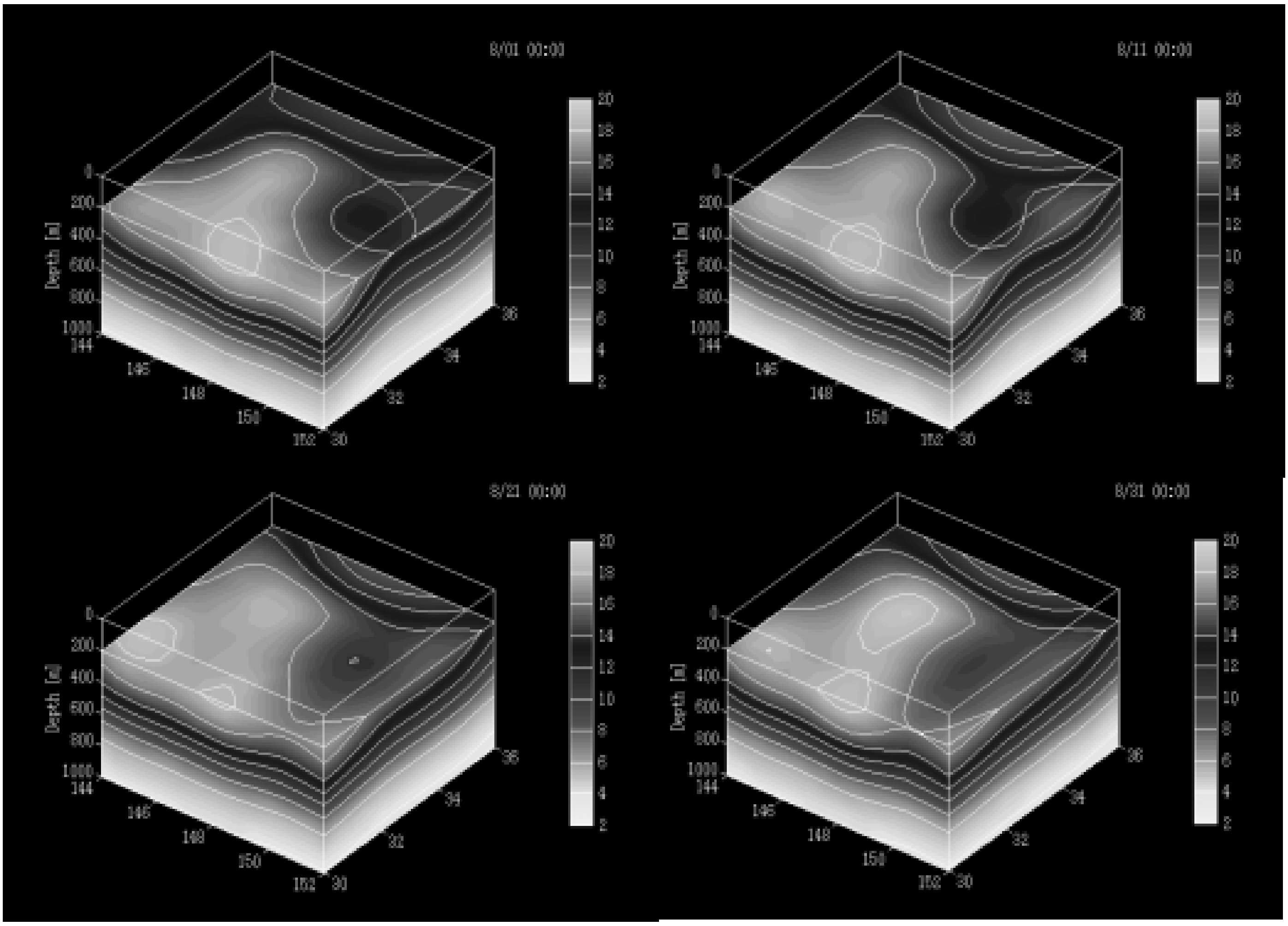


Fig. 12 Examples of the results for 3-dimensional distrubution of water temperature in the arer of the between latitude 144°E and 152°E and the between longitude 30°N and 36°N measured on August 1, 11, 21 and 31. The horizontal plane is sliced at a depth of 200 m.

developed. We deployed them in the east of the Izu-Ogasawara Trench for the system operation tests during July and September in 1997 and achieved a real-time observation. Three-dimensional measurements are realized by using the present five tomography transceiver systems. We are now conducting the experiment using seven transceivers in the Central Equatorial Pacific for two years. Hereafter, this tomography system is expected to be useful for predicting global climate change.

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